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A PRELIMINARY NOTE ON THE INTERNAL PARASITES OF PUERTO RICAN CATTLE WITH SPECIAL REFERENCE TO THOSE SPECIES FOUND IN CALVES SUFFERING FROM "TROPICAL DIARRHEA" *

By John S. Andrews
and
José F. Maldonado

INTRODUCTION

In Puerto Rico many calves suffer from a condition locally known as "tropical diarrhea." This condition, according to information obtained from farmers who are familiar with its clinical aspects, usually appears in young calves shortly after they have been turned out to pasture. The affected animals develop anorexia, diarrhea, and anemia, become weak and emaciated, and many of them die. In some sections of the Island "tropical diarrhea" has made the raising of calves almost impossible, with the result that many dairymen have been forced to buy cattle locally or to import them in order to replace normal losses in their herds.

In December 1938 the Puerto Rico Agricultural Experiment Station in cooperation with the School of Tropical Medicine, began a series of investigations to determine the relationship between the occurrence of "tropical diarrhea" in cattle on the island and the presence of infestations with gastro-intestinal parasites in the affected animals. Although Dikmans (3) and Van Volkenberg (10, 18) published the results of parasitological examinations of cattle in the vicinity of Mayaguez, P. R. and Catalá (2) and Van Volkenberg (10, 11, 12, 13, 14, 15, 16, 17) associated certain parasites with definite clinical symptoms of disease, the specific relationship between the presence of these parasites and the syndrome called "tropical diarrhea" was not studied by these workers. It was, therefore, necessary to undertake a survey as a preliminary step

* Cooperative project between the Agricultural Experiment Station of the University of Puerto Rico and the School of Tropical Medicine.

in the present study of "tropical diarrhea" in order to identify the parasites occurring in the affected animals. The species which appeared to have a causal relationship to the condition could then be selected for further experimental investigation.

A list of parasites collected during this survey has already been published in the Annual Report of the Puerto Rico Agricultural Experiment station for 1938-39, and a supplementary list is now in press as part of the Report for 1939-40. Detailed information concerning the frequency of the occurrence of the parasites encountered or the relative importance of these species found in calves suffering from "tropical diarrhea," however, was not included in these reports. This information plus data on the ages of the animals affected and the geographical and seasonal distribution of the cases of "tropical diarrhea" observed are included in the present note. Since these data for the most part were obtained from calves voluntarily sacrificed by the owners, they are not as comprehensive as might be desired. They appear, however, to furnish a basis for further experimental work on the problem.

Data Obtained

Twenty-two calves were autopsied during this survey. The species of parasites recovered from these calves arranged in order of their occurrence, but without regard to the severity of the individual infestations, are recorded in table 1.

TABLE 1. THE INTERNAL PARASITES RECOVERED AT AUTOPSY FROM 22 CALVES ARRANGED ACCORDING TO THE FREQUENCY OF THEIR OCCURRENCE IN THESE ANIMALS

Name of parasite	Organ parasitized	Number of calves infested	Percentage of calves infested
Bunostomum phlebotomum	Small intestine	17	77.3
Oesophagostomum radiatum	Large intestine	14	63.6
Cooperia punctata	Small intestine	12	54.5
Haemonchus contortus	Abomasum	11	50.0
Trichuris ovis	Large intestine	9	40.9
Dictyocaulus viviparus	Lungs	5	22.7
Haemonchus similis	Abomasum	5	22.7
Moniezia spp.	Small intestine	5	22.7
Ostertagia ostertagi	Abomasum	4	18.0
Setaria labiatopapillosa	Body cavity	3	13.6
Strongyloides papillosus	Small intestine	3	13.6
Trichostrongylus axei	Abomasum and small intestine	3	13.6
Capillaria longipes	Small intestine	2	9.0
Capillaria sp.	Small intestine	2	9.0
Cooperia curticei	Small intestine	2	9.0
Cooperia pectinata	Small intestine	2	9.0
Eimeria zurni	Large intestine	2	9.0
Fasciola hepatica	Liver	2	9.0
Syngamus laryngeus	Trachea	2	9.0
Cotylophoron cotylophorum	Rumen	1	4.5
Trichostrongylus colubriformis	Small intestine	1	4.5

The data in table 1 show that the four gastro-intestinal parasites occurring most frequently in the 22 calves were *Bunostomum phlebotomum,* the common hookworm of cattle, *Oesophagostomum radiatum,* the nodular worm, *Cooperia punctata,* a small nematode living in the small intestine, and *Haemonchus contortus,* the large stomach worm, respectively. As shown in table 2, these same four species of parasites were also recovered in relatively large numbers from calves suffering from "tropical diarrhea." With the exception of *Dictyocaulus viviparus,* the lungworm, which was found to be the cause of verminous pneumonia in 3 calves, and *Eimeria zurni,* a coccidium, which will be discussed in connection with the data given in table 2, the remainder of the parasites shown in table 1 were present in such small numbers as to be of little pathogenic importance.

Eight of the 22 calves autopsied were found to be suffering from "tropical diarrhea" as was indicated by the presence of typical symptoms of the disease. The data obtained from these 8 calves together with data from another calf which could not be autopsied are recorded in table 2.

According to the data in table 2, the calves suffering from "tropical diarrhea" ranged in age from 2 to 11 months. Eight of the 9 cases were observed during the first 3 months of the calendar year. Only one case was seen as late as June. Five of the affected calves came from the Central mountainous region of the Island, 2 came from the North and 2 from the South coastal plain.

TABLE 2. DATA OBTAINED FROM CALVES SUFFERING FROM "TROPICAL DIARRHEA"

Calf No.	Approximate age in months	Date of examination	Geographical location	Species of gastro-intestinal parasites recovered					
				Haemonchus contortus	*Bunostomum phlebotomum*	*Cooperia punctata*	*Strongyloides papillosus*	*Oesophagostomum radiatum*	*Eimeria zurni*
1	2	1/20/39	Cayey-Central mountainous section	2,000	326	very few	0	0	0
2	10	1/20/39	Cayey-Central mountainous section	6	33	3,000	0	0	0
3[1]	2	6/16/39	Morovis-Central mountainous section	0	0	0	x[2]	0	x
4	3	1/15/40	Palo Seco-North coastal plain	0	1	5,000	0	0	0
5	4	2/1/40	Bayamón-North coastal plain	267	57	6,000	0	0	0
6	8-9	2/16/40	Orocovis-Central mountainous section	0	800	126,000	0	6,000	0
7	8-9	2/16/40	Orocovis-Central mountainous section	0	80	very few	0	47	0
8	10-11	3/15/40	Ponce-South coastal plain	0	136	very few	0	1	x
9	10-11	3/15/40	Ponce-South coastal plain	0	5	very few	0	88	x

[1] The data from calf 3 were obtained from fecal samples.
[2] "x" is used to denote heavy infestations which could not be expressed numerically.

DISCUSSION OF INDIVIDUAL CASES

Calf 1

Calf 1 was approximately 2 months old and died on the night of January 19, 1939, weighing less than when it was born according to the owner. It had been on a hillside pasture consisting of malojillo grass (*Panicum purpuracens Raddi*) with its mother since birth. It had suffered from diarrhea for some time and at autopsy it was found to be very anemic. The three species of gastro-intestinal parasites harbored by this calf which were also recovered from other calves suffering from diarrhea are listed in table 2.

Since calf 1 received practically all of its nourishment from the cow the symptoms observed did not appear to be due to malnutrition. However, the stomach-worm and hookworm infestations, which had undoubtedly been picked up from the pasture, seemed to be sufficient to account for the symptoms observed. The anemia present could very easily have been caused by these nematodes alone, since both species are known to cause severe hemorrhage. It is also probable that the hookworm infestation was a factor in the production of the diarrhea. The infestation with *C. punctata,* on the other hand, was considered to be too small to be of any pathogenic importance, although the findings of Ransom (6), Hung (5), and Dikmans (4) have indicated that this species is capable of causing extensive lesions in the wall of the small intestine of heavily infested calves.

Calf 2

Calf 2 was 10 months old at the time it was killed for autopsy. It had been grazing on a malojillo pasture without proper supplementary feeding and was suffering from diarrhea but was not anemic. It was extremely small for its age and was in very poor physical condition.

Although the lack of proper feeding was undoubtedly partly responsible for the small size of this calf, it is almost certain that the relatively large infestation with *C. punctata* observed contributed to the production of the diarrhea. (See references mentioned in connection with the discussion of the data obtained from Calf 1.) The absence of anemia together with the very light infestations with stomach-worms and hookworms strengthens the hypothesis that the anemia in calf 1 was largely due to infestation with these two species of parasites.

Calf 3

Calf 3 was about 2 months old and was suffering from a severe and very bloody diarrhea at the time of observation. This calf could not be

autopsied, but fecal samples were obtained and examined for evidences of parasitic infestation. Great numbers of eggs of *Strongyloides papillosus,* together with thousands of merozoites and oocysts of *Eimeria zurni* were found in the feces.

Since, so far as could be ascertained, the diet of this calf was satisfactory, the observed pathological condition appeared to be caused primarily by the coccidial infestation. The effects of the *Strongyloides* infestation, however, cannot be ruled out entirely, since this nematode has been reported by Roberts (*7*) as responsible for diarrhea in a 3-months-old calf.

Calf 4

Calf 4 was about 3 months old and had been raised for the first 2 months of its life in a pen having a concrete floor. During this period it had been fed milk from a bucket and was occasionally allowed access to a grass plot near the pen. For the month previous to autopsy it had grazed with other calves in a nearby grapefruit grove. The calf was very thin and weak, but was not anemic. It had a persistent cough and was suffering from diarrhea at the time of autopsy.

Although pneumonia was apparently the fundamental cause of the unthrifty condition of this calf, the relatively heavy infestation with *C. punctata* was undoubtedly responsible for the diarrhea observed.

Calf 5

Calf 5 was about 4 months old and had been raised with several other calves on a luxuriant malojillo pasture. Seven of the calves belonging to this group had died within the previous 3 months with symptoms of diarrhea and weakness. Calf 5 had been on the pasture for 3 months and had had diarrhea for 1 month prior to autopsy. It weighed approximately 50 per cent of normal but was not anemic.

At autopsy a relatively heavy infestation with *C. punctata* was found which was apparently responsible for the diarrhea observed. The infestations with stomach-worms and hookworms were too light to have contributed to the pathological picture.

Calves 6 and 7

These two calves were between 8 and 9 months old and belonged to a group of 30 calves which had been brought to the mountains 5 to 6 months previously. They had been put on a pasture containing malojillo and elephant grass (*Pennisetum purpureum Schum*), but were given no supplementary ration. Eleven of the 30 calves had died during the previous month. The remaining animals were thin and weak. Some of

them were anemic and exhibited the characteristic "bottle-jaw" seen in many such cases.

Calf 6 was very anemic and was suffering from severe diarrhea at the time of autopsy. As is shown in table 2, this calf harbored the heaviest parasitic infestation encountered. Hookworms, *C. punctata,* and nodular worms were present in such large numbers that the condition of the calf could not be ascribed to any one species. Sections of the small intestine revealed larvae of *C. punctata* in the mucosa showing, for the first time during the present study, that this nematode was causing definite pathological changes.

Calf 7 was in a much poorer physical condition than calf 6. It was also suffering from diarrhea, but did not exhibit as severe an anemia. Although the number of adult parasites recovered was relatively insignificant, there was an incipient *O. radiatum* infestation. The inflamed and edematous condition of the ileum and cecum caused by the larvae of this nematode appeared to be sufficient to account for the diarrhea observed.

Although these calves received no supplementary ration, the pasture was in good condition so that very little if any of the symptoms observed could be attributed to malnutrition It appears, therefore, that the symptoms observed in these two calves were primarily due to the nematode infestations harbored. The difference in the parasitic infestations found in calves 6 and 7 is indeed remarkable considering the fact that both animals grazed the same pasture under the same conditions for approximately the same length of time. This fact coupled with the observation that the physical condition of calf 7 was worse than that of calf 6 seems to point to the great importance of individual differences in the response of the animals concerned, not only to the kind of feed available, but to the effects of parasitic infestations harbored.

Calves 8 and 9

These two calves were grade Brahmas between 10 and 11 months old and were taken for autopsy from two farms having no direct connection. The calves were not in good physical condition because of the extreme dryness of the pasture which served as their only source of food. Water was obtained from isolated water holes which were contaminated with the feces of the animals drinking from them. These two calves were suffering from a severe diarrhea but were not anemic.

Both calves were found at autopsy to be infected with *Eimeria zurni,* a common cattle coccidium. The wall of the cecum in the neighborhood of the ileocecal valve was thickened and hemorrhagic, and was teeming

with merozoites and oocysts of *E. zurni*. Since the number of other species of parasites was negligible, the coccidial infection alone appeared to be responsible for the diarrhea observed in these animals.

Infestations with *E. zurni* are very often found in healthy cattle which apparently have sufficient natural resistance to prevent these parasites from becoming pathogenic. In the case of calves 8 and 9, however, the prevailing dry weather conditions had apparently so reduced the nutritive value of the pasture that the resistance of these animals was lowered to the point where the parasites were able to become pathogenic and to produce clinical symptoms.

DISCUSSION

The foregoing data show that all of the cases of "tropical diarrhea" observed occurred in calves from 2 to 11 months old, and that the condition was not limited to any one region of the island. Although 8 of the 9 cases were observed during the first 3 months of the calendar year, this condition cannot be said to be "seasonal" since there are no definite seasons in Puerto Rico which are comparable to those in temperate zones. The data further indicate that the cases of "tropical diarrhea" studied can be classified into 3 groups as follows:

Group 1, in which malnutrition was apparently a complicating factor.

Calf No.	*Gastro-intestinal parasites present*
2	*Cooperia punctata*
8	*Eimeria zurni*
9	*Eimeria zurni*

Group 2, in which bacterial infection was apparently a complicating factor.

4	*Cooperia punctata*

Group, 3 in which there was no apparent complicating factor.

1	*Haemonchus contortus* *Bunostomum phlebotomum*
3	*Eimeria zurni* *Strongyloides papillosus*
5	*Cooperia punctata*
6	*Bunostomum phlebotomum* *Cooperia punctata* *Oesophagostomum radiatum*
7	*Bunostomum phlebotomum* *Oesophagostomum radiatum*

These results show that the cases of "tropical diarrhea" observed during this study, although sometimes complicated by malnutrition or bacterial infection, were always associated with relatively large infesta-

tions consisting of one or more of six species of gastro-intestinal parasites, namely, *B. phlebotomum, O. radiatum, C. punctata, H. contortus, S. papillosus,* and *E. zurni.*

Catalá (2) stated that the principal internal parasites found by him in Puerto Rican calves suffering from diarrhea, anemia, and emaciation were *O. radiatum, Uncinaria radiata* (*B. phlebotomum*), and *Ascaris vitulorum.* Van Volkenberg (15) considered *B. phlebotomum, O. radiatum, H. contortus,* and *Eimeria* spp. of pathogenic importance in Puerto Rican cattle. Although he admitted the possible injurious effects of *C. punctata* and *S. papillosus,* this author felt that these two species were of relatively less importance than the parasites previously mentioned by him. In addition Van Volkenberg reported *Moniezia expansa* and the young forms of *C. cotylophorum* as associated with cases of diarrhea in calves.

Roberts (7) recovered 11 species of gastro-intestinal helminths from Australian cattle which he considered of pathogenic importance. These parasites were associated with diarrhea, anemia, and, in some instances, with emaciation, occurring in calves 4 to 12 months old. Five of these 11 species have already been mentioned in connection with the results obtained from the present survey. Six species, *O. ostertagi, T. axei, C. pectinata, Moniezia benedeni,* the young forms of *Paramphistomum cervi* and *P. explanatum; Cooperia oncophora,* reported by Baker (1), *Nematodirus helvetianus,* reported together with *C. oncophora* and coccidia, by Tunnicliff (9), as the apparent cause of diarrhea in calves; and an unidentified species, which may be *Mecistocirrus digitatus,* reported by Sheather (8) as pathogenic for Indian calves (according to Roberts), have not yet been associated with "tropical diarrhea" as it occurs in Puerto Rico.

Roberts (7) has pointed out that 3 of the 6 species recovered from the cases of "tropical diarrhea," observed during the present study, namely, *B. phlebotomum, O. radiatum* and *H. contortus* have been repeatedly associated with cases of parasitic gastro-enteritis calves. As has been shown earlier in this paper the remaining 3 species have also been recovered from diarrheic calves by other workers. Since the symptoms shown by calves suffering from "tropical diarrhea" were found to be very similar to those reported for calves in temperate climates known to be suffering from parasitic gastro-enteritis, and since the species of parasites recovered from typical cases of "tropical diarrhea" have also been found in calves known to be suffering from parasitic gastro-enteritis, the present observations appear to suggest the possibility that "tropical diarrhea" of cattle in Puerto Rico may be caused by para-

sitic infestation. If this hypothesis is proved to be correct, the number of different species of parasites associated with this condition will undoubtedly be increased as additional cases are studied.

CONCLUSIONS

1. "Tropical diarrhea" so far as the condition in Puerto Rico is concerned is not a specific disease entity. It does not differ in any way from similar conditions occurring in cattle in temperate zones.

2. It is not seasonal in occurrence, nor is it confined to any definite portion of the island.

3. "Tropical diarrhea" as it occurs in Puerto Rico, may be due to infestation with various animal parasites.

4. The fact that 4 of the 6 species of gastro-intestinal parasites found in the calves suffering from "tropical diarrhea" were the species found most frequently in all of the calves examined, suggests that their probable relation to the disease should be further investigated.

SUMMARY

The results of a survey of the internal parasites of Puerto Rican cattle made as a preliminary step in connection with investigations on "tropical diarrhea" in calves have shown that the four most common species of gastro-intestinal parasites in the 22 calves autopsied were, *B. phlebotomum* (77.3%), *O. radiatum* (63.6%), *C. punctata* (54.5%), and *H. contortus* (50%).

Eight of the 22 calves and one calf not autopsied were found to be suffering from "tropical diarrhea." These nine calves were from 2 to 11 months old and were about evenly divided between the central mountainous section and the north and south coastal plains. Eight of the nine cases occurred during the first 3 months of the calendar year. One occurred in June.

E. zurni, together with the four species of nematodes just mentioned were recovered in large numbers from calves suffering from "tropical diarrhea." The nematode, *S. papillosus*, was also implicated in one case as the result of finding large numbers of eggs in the feces of a calf. The remainder of the 21 species of parasites listed, with the exception of the lung worm, *D. viviparus*, which was found to be the cause of verminous pneumonia in 3 calves, were considered to be of little pathogenic importance in the calves examined.

Three of the 9 cases of "tropical diarrhea" appeared to be due to a combination of malnutrition and heavy infestation with gastro-intestinal

parasites. One case was apparently caused by gastro-intestinal parasites combined with bacterial infection (pneumonia), and 5 cases appeared to be due to infestation with gastro-intestinal parasites alone.

Twelve species of parasites in addition to the 6 already mentioned have been reported by other workers as apparently responsible for cases of gastro-enteritis in calves, namely, *O. ostertagi, T. axei, C. oncophora, C. pectinata, N. helvetianus, A. vitulorum, M. benedeni, M. expansa, M. digitatus,* and the young forms of *C. cotylophorum, P. cervi,* and *P. explanatum. C. oncophora, N. helvetianus, A. vitulorum, M. digitatus* and the young forms of the 3 species of trematodes were not encountered in any of the calves autopsied. The remaining parasites were present in such small numbers that they were considered to be of little pathogenic importance.

It was concluded that since "tropical diarrhea" does not differ from similar conditions occurring in calves in temperate zones which have been definitely associated with infestation with gastro-intestinal parasites, and, since 4 of the 6 species of parasites found to be present in large numbers in calves suffering from this condition, were the species found most commonly in all of the calves examined, that the probable relationship of parasitic infestation to "tropical diarrhea" should be further investigated.

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SUMARIO

Los resultados obtenidos en un reconocimiento, como estudio preliminar de los parásitos internos del ganado bovino, para investigaciones en relación con las "diarréas tropicales" de los becerros nos demuestran, juzgando por los 22 animales examinados en sus autopsias, que los cuatro parásitos gastrointestinales mencionados a continuación son los encontrados más comunmente: el *Bunostomum phlebotomum* (77.3%), el *Osophagostomum radiatum* (63.6%), el *Cooperia punctata* (54.5%), y el *Haemonshus contortus* (50%).

Ocho de los becerros examinados en autopsias más uno sin examen *post-morten* estaban afectados con "diarréas tropicales." Estos nueve becerros fluctuaban entre 2 a 11 meses de edad y su procedencia puede decirse que es representativa de las condiciones de la isla porque provenían de las secciones montañosas del centro de la isla, así como del litoral Norte y Sur. Ocho de los nueve casos se manifestaron durante los tres primeros meses del año natural y el otro en junio.

El organismo *Eimeria zurni* siempre se encontraba presente en los casos de "diarréas tropicales" conjuntamente con los otros cuatro nematodos mencionados. El nematodo *Strongyloides papillosus* fué también muy notable en un caso, como resultado de encontrarse un gran número de sus huevos en las heces fecales de un becerro. El resto de las 21 especies de parásitos internos en la lista, con la excepción del gusano o bichillo pulmonar, *Dictyocaulus viviparus,* el cual hemos encontrado que

es causante de la pulmonía verminosa en tres becerros, los consideramos de poca importancia patogénica en todos los animales examinados.

Tres de los nueve casos de "diarréas tropicales" parece que son causados por una combinación de mala nutrición e infecciones fuertes de los parásitos gastrointestinales. Un solo caso aparecía como causado por parásitos gastrointestinales combinado con infecciones bacteriológicas (pneumonia) y cinco de ellos se encontraron ser causados por infecciones de parásitos gastrointestinales solamente.

Otros investigadores han encontrado doce especies de parásitos gastrointestinales, además de los seis mencionados por nosotros como consecuentes de trastornos de gastroenteritis de los becerros.

Estos parásitos son: *Ostertagia ostertagi, Trichostrongylus axei, C. oncophora, C. pectinata, N. helvetianus, A. vitulorum, M. benedeni, M. expansa, M. digitatus y las formas juveniles del C. cotylophorum, P. cervi y P. explanatum. C. oncophora, N. helvetianus, A. vitulorum, M. digitatus* y las formas juveniles de los tres trematodos o sea, los estados iniciales, no se encontraron en ningún momento en las autopsias de los becerros examinados. Todos los demás parásitos internos presentes en los exámenes fueron en tan pequeño número o escasa importancia que no le hemos dado ninguna importancia patogénica.

Se llegó a la conclusión, que dado el caso de que las "diarréas tropicales" no se diferencian de los casos similares ocurrentes en becerros de la zona templada, los cuales se asocian definitivamente con infecciones de parásitos gastrointestinales y toda vez que 4 de las 6 especies de parásitos encontrados se hallaban en gran número en todos los becerros enfermos, siendo a la vez las especies que se encontraban más comunmente en todos los exámenes. La relación probable entre infecciones parasitarias y las "diarréas tropicales" debe seguir investigándose.

THE EFFECT OF TEMPERATURE UPON THE BASE-EXCHANGE CAPACITY OF CLAYS

By Angel Alberto Colón
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INTRODUCTION

Soils, when brought into contact with certain solutions, undergo certain reactions in which the removal of cations from the soil and their replacement by cations from the solution are involved. The most important cations found in soils are usually calcium, sodium, potassium, magnesium, and acid hydrogen. When any one of these cations is replaced by another particular cation, an exchange of cations has taken place; since these cations are mainly basic, the name base-exchange is applied to this process. Next to photosynthesis base-exchange is the most important chemical reaction in the whole domain of agriculture. Naturally, when one cation is replaced by another in the soil, marked changes in the physical and chemical properties of the soil take place as shown by the relative crop producing power of the soil. Therefore, the availability of these "bases" has a direct relation to the fertility; and any condition that affects the base-exchange capacity of the soil is of great importance.

It has been known for a long time that the removal of water from the soil such as occurs commonly in Puerto Rico, Louisiana, and other places of the earth having high summer temperatures, brings about far reaching changes in the availability of some of the essential soil constituents; hence producing a marked effect upon the fertility of the soil. It has generally been believed that the high temperature to which the land is subjected in the torrid zones have the priceless effect of making the land more productive by setting free some of the reserve plant food.

Although there has been an enormous amount of work done recently dealing with the different aspects of the subject, much of it is vague, and a great part is contradictory. It was thus the purpose of this work to attempt to obtain further data on the effect of temperature upon the base-exchange capacity of soils.

The base-exchange capacity of a soil can be determined by adding an excess of a solution of a replacing salt, like ammonium acetate, to the soil; and, by taking advantage of the exchange reaction which occurs between the ammonium acetate and the soil, the total content of the replaceable bases present in the soil can be readily determined. In order for

this exchange of bases to proceed to completion it is necessary to use a sufficiently concentrated solution of replacing salt. For ammonium acetate this concentration is approximately one normal. "Since the exchange takes place stoichiometrically, the amount of ammonium absorbed by the soil is chemically equivalent to the sum of all the bases replaced." (6)

But the base-exchange capacity of soil is not constant, it varies in accordance with several factors. Thus Magistad (9) found it to vary with "reaction of soil, moisture, and other factors" which he explained as being due to a building-up and tearing-down of the particles. Wiegner (19) observed that "the hydration of the ions is the cause of their exchange capacity." Perkins and King (12) found that "the base held by a soil had a considerable effect on its capacity to hold water."

Heat is another important factor influencing base-exchange capacity of soils. It may be looked upon in two different ways: intensity of heat, or temperature, and time of heating. Concerning the effect of heat upon the base-exchange capacity there seems to be some contradiction. Steenkamp (17) found that the total exchangeable bases and the degree of saturation of the soils were increased on drying, and that such soils showed a corresponding decrease in acidity. Coles and Morrison (3) repeated Steenkamp's work and found that the effect of heat and dehydration upon the acidity of suspensions of soils showed an increase in acidity accompanied by a decrease in the content of exchangeable bases, and an increase in the amount of those bases present in contact with the soil; and that the total exchangeable bases in the soil were less after heating the soil in the steam oven than in the original soil.

This exchange of bases takes place mainly on the surfaces or interfaces of small soil particles which are of nearly colloidal dimensions. These particles have a maximum diameter of about 0.002 mm. (colloidal size being generally accepted to be about 0.0001 mm. or 0.1μ and are called the clay fraction of the soil. It so happens that this dynamic clay fraction forms only a very small part of the soil, and hence it would seem desirable to work with the clay fraction alone in order to obtain more pronounced effects.

MATERIALS AND METHODS

In order to obtain this so-called colloidal fraction, the soil was dispersed with 0.8 molar ammonium hydroxide in a rotary shaker for 24 hours; the so dispersed soil was allowed to settle for at least another 24 hours and the upper layer of the suspension, to a depth of 9 cm., was siphoned off. According to Stoke's law for particles falling through a

column of fluid, particles of diameters of about 0.002 mm. will settle 8.6 cm. in 24 hours; therefore any particle that has not settled this depth in 24 hours is considered to be a clay and in agricultural dialect, "colloidal." The clay fraction was coagulated by addition of calcium chloride, and the coagulated colloids then concentrated by supercentrifuging. The colloids were then divided into groups and each group saturated with one of the chlorides of K, Na, Ca, Mg, and with hydrochloric acid, followed by centrifuging to separate the colloid from the rest of the saturating solution. The colloids were then washed with equal volumes of water until practically free of chlorides (this was to remove excess salt).

On samples of each type of clay, base-exchange capacity and total exchangeable bases were determined before any heating.

In each of four ovens at 25°, 50°, 75°, and 100° C, respectively, samples of the different clays were placed and heated for 5, 12, and 46 days; and on each sample base-exchange and total exchangeable bases were determined.

Potassium clay. Potassium was determined by precipitation and weighing as potassium-sodium-cobalti-nitrite according to the method of Addie and Wood (1) as used by Van Rysselberge. (18)

Sodium clay. Sodium was determined by precipitation and weighing as the triple salt sodium-uranyl-magnesium-acetate as recommended by Piper. (13)

Calcium clay. Calcium was determined by precipitation as calcium oxalate in an alkaline solution, washing the precipitate free of any excess ammonium oxalate; dissolving the precipitate in hot concentrated sulfuric acid, and titrating the oxalic acid formed with standard potassium permanganate.

Magnesium clay. Magnesium was determined by precipitation as magnesium ammonium phosphate, ignited, and weighed as magnesium pyrophosphate. (2, 8)

Hydrogen clay. Acid hydrogen was determined by direct titration with standard sodium hydroxide using methyl red as an indicator.

The base exchange capacity was determined by adding fifty milliliters of a neutral solution of ammonium acetate, as recommended by Schollenberger and Dreibelbis (16), to the sample; the contents were well stirred, and the replacing reaction allowed to proceed overnight (it is generally accepted that the exchange reaction takes place quantitatively within the first five minutes). In the case of the hydrogen clay the solution used for replacing the absorbed ions was normal-neutral barium acetate. (20)

In every case the total exchangeable bases were determined by boiling with concentrated sodium hydroxide in a Kjeldahl apparatus, absorbing the evolved ammonia in boric acid solution, and titrating directly with standard sulfuric acid using methyl red as indicator.

RESULTS

In the potassium clay the amount of replaceable potassium was found to decrease from 40.8 milliequivalents (me.) at 0 days to 31.93 me. after 46 days heating at 25° C. For any one temperature there was a decrease in the amount of replaceable potassium upon prolongation of the time of heating.

The temperature also showed a marked effect, decreasing the amount of replaceable potassium. For clays heated during the same length of time, the one heated at the highest temperature (100° C.) showed the smallest amount of replaceable potassium, that is, the largest decrease. For instance, with the clays treated for 46 days, the amount of replaceable K was 31.93 me. for the clay heated at 25° C., and only 26.9 me. for the 100° C. clay. (See table 1.)

TABLE 1. MILLIEQUIVALENTS OF K/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	40.80	34.51	32.76	31.93
50°C	40.80	32.81	31.95	31.10
75°C	40.80	32.29	30.54	29.48
100°C	40.80	30.67	29.16	26.90

The total replaceable bases on the other hand, showed a marked increase upon prolonged heating. Thus the samples heated at 25° C. increased from 96.53 me. at 25°C. to 88.23 me. at 100° C. (See table 2.)

TABLE 2. MILLIEQUIVALENTS OF BASES/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	78.37	87.45	94.98	96.53
50°C	78.37	85.17	88.33	95.60
75°C	78.37	80.45	87.45	90.83
100°C	78.37	78.42	86.78	88.23

Note: The samples of the K clays were all of the same weight—1.8939 g. when dry.

In the sodium clay there was an increase in the amount of exchangeable sodium present both upon prolonged and intense heating. For example, the samples heated at 25° C. showed an increase from 30.86 me. at 0 days to 40.04 me. after 46 days of heating. For the samples heated at the same temperature but for different lengths of time: the samples heated for 46 days gave 40.04 me. at 25° C. and 41.37 at 100° C. (See table 3.)

TABLE 3. MILLIEQUIVALENTS OF Na/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	30.86	34.53	36.08	40.04
50°C	30.86	36.22	39.31	41.40
75°C	30.86	33.90	38.46	41.13
100°C	30.86	34.87	40.31	41.37

The total exchangeable bases in the case of the sodium saturated clay showed a regular decrease in the amount of replaceable bases both upon prolonged heating and upon increasing the temperature; thus for the clays heated at 25° C., the one at 0 days gave a value of 92.63 me. while that heated for 46 days only gave 59.20 me. of replaceable bases. For the samples treated for the same length of time, those heated at 25° C. gave 59.20 me. and those at 100° C. gave 47.84 me. when both had been heated for 46 days. (See table 4.)

TABLE 4. MILLIEQUIVALENTS OF BASES/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	92.63	80.79	66.50	59.20
50°C	92.63	89.42	74.00	62.90
75°C	92.63	78.22	57.54	50.86
100°C	92.63	75.85	56.12	47.84

Note: The samples of the Na clays were all of the same weight—1.5887 g. when dry.

The calcium clay showed a decrease in the amount of replaceable calcium upon prolonged heating at the same temperature; thus the samples heated at 25° C. decreased from 41.11 me. at 0 days to 28.12 me. after 46 days heating. (See table 5.)

TABLE 5. MILLIEQUIVALENTS OF Ca/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	41.11	32.08	31.66	28.12
50°C	41.11	41.01	40.28	37.47
75°C	41.11	31.72	26.32	26.32
100°C	41.11	32.21	31.50	30.34

The total exchangeable bases showed a slight decrease upon prolonged heating at the same temperature; thus at 25° C. the samples had 78.95 me. at 0 days and only 55.73 me. after 46 days of heating. (See table 6.)

TABLE 6. MILLIEQUIVALENTS OF BASES/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	78.95	61.59	60.85	55.73
50°C	78.95	71.44	67.44	66.64
75°C	78.95	62.39	57.89	57.77
100°C	78.95	63.00	62.20	61.59

Note: The samples of the calcium clays were all of the same weight—1.5960 g. when dry.

In the case of the magnesium clays it was found that the amount of replaceable magnesium increased upon prolonged heating at any one temperature. Thus the clays heated at 25° C. increased from 34.80 me. of replaceable magnesium at 0 days to 43.58 me. after 46 days of heating.

An increase in temperature had no appreciable effect upon the amount of replaceable magnesium: Thus after 46 days heating the 25° C. clay showed 43.58 me. of replaceable Mg. whereas the 100° C. sample gave a value of 42.04 me. (See table 7.)

TABLE 7. MILLIEQUIVALENTS OF Mg/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	34.80	38.56	40.88	43.58
50°C	34.80	39.58	41.52	44.63
75°C	34.80	39.18	36.22	41.14
100°C	34.80	37.38	41.39	42.04

The total exchangeable bases showed a large increase with prolonged heating. Thus at 25° C. the 0 days sample had 50.96 me. and while the 46 days sample had 63.85 me. An increase in temperature also brought an increase in the amount of replaceable bases; thus after 46 days of heating the sample at 25° C. gave a value of 63.86 me. while the sample at 100° C. showed 89.92 me. of replaceable bases (See table 8.)

TABLE 8. MILLIEQUIVALENTS OF BASES/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	50.98	53.10	63.01	63.86
50°C	50.98	54.87	66.55	68.68
75°C	50.98	72.92	80.71	85.31
100°C	50.98	81.77	84.61	89.92

Note: The samples in the magnesium clays were all of the same weight—1.3886 g. when dry.

In the acid hydrogen clays the amount of replaceable hydrogen decreased upon prolonged heating. Thus the samples treated at 25° C. showed 28.45 me. of replaceable hydrogen at 0 days and only 7.17 me. after 46 days heating. (See table 9.)

TABLE 9. MILLIEQUIVALENTS OF H/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	28.45	20.52	10.93	7.17
50°C	28.45	15.64	9.08	7.01
75°C	28.45	16.41	14.91	8.27
100°C	28.45	15.01	13.49	6.90

The total exchangeable bases showed an increase upon prolonged heating. Thus the samples heated at 25° C. increased from 42.06 me. of

replaceable bases at 0 days to 101.44 me. after 46 days of heating. (See table 10.)

TABLE 10. MILLIEQUIVALENTS OF BASES/100 G. OF CLAY

Tempt.	0 Days	5 Days	12 Days	46 Days
25°C	42.06	62.68	76.70	101.44
50°C	42.06	45.44	51.13	84.94
75°C	42.06	48.00	52.78	87.42
100°C	42.06	45.77	52.78	69.44

Note: The samples in the H clays were all of the same weight—1.1917 g. when dry.

DISCUSSION

In order to understand the changes effected by heat upon the clay complex, it is first necessary to know the nature of the colloids. It was the assumption of earlier workers on soils that the clay was amorphous in character, but recent works point to a crystalline structure. Powell (14) questioned the emulsoid nature of clays on the basis of viscosity determinations. Ross (15), using X-rays observed that clays have a crystalline nature; and his work was corroborated by that of Hendricks and Fry (4). Marshall (10) brought forward further evidence supporting the crystalline nature of clays (from a study of their refractive properties) and concluded that exchange cations are present in the interior of the crystal as well as on the surface.

These minerals exhibit a platy crystalline structure analogous to mica, and it may be maintained that this structure, involving large surface development and large contact areas between particles is sufficient to explain the properties of the clay. Besides the presence of cations on the inner and outer surfaces of the crystals, it has been shown by Kelley, Dore and Brown (7) that there are inner, non-exchangeable cations present within the lattice of the crystalline plates, which can be set free under conditions that would cause the rupture of the crystals, such as intensive grinding. Hoffman, Endell, and Wilm (5) have shown that the distance between the crystalline plates of a clay colloid varies with moisture content.

It is natural that as we heat the clay, the crystalline plates move closer together due to a loss of water. It appears that when these plates move closer together they trap some of the exchangeable cations that were present between the plates thus rendering them non-replaceable. This was the case with the calcium and potassium clays (and H clays), which showed a decided decrease in their amounts of replaceable cations present upon prolonged heating.

There may be, however, another effect produced by the heating; the plates may move closer together due to the loss of water, but if the heating were too intense, or if the crystalline structure were somewhat unstable (due perhaps to the very nature of the absorbed cations) then the atomic vibrations within the crystal lattice increase to a point where the whole structure collapses. At this moment the cations that were originally inside the crystalline lattice, and which were non-replaceable, now are set free and become replaceable; and thus the apparent total amount of the particular cations determined is found to increase considerably. This was the case with the sodium and magnesium clays where a marked increase in the amount of the exchangeable cation was found after prolonged thermal treatment.

Ions with small ionic radius (11) (sodium 0.95Å, and magnesium 0.65Å) tend to become more available upon heating. That is, they cause instability and rupture of the crystalline structure. Ions with larger ionic radii (calcium 0.99Å, and potassium 1.33Å) are rendered unavailable by heat. The hydrogen ion does not obey this rule, but then hydrogen never behaves normally considering its small radius.

SUMMARY

The purpose of this work was to obtain data that would throw light upon the nature of the changes brought about by heat on the base exchange capacity of soils.

The clay fraction of a Crowley silt loam soil was obtained, divided into five equal portions, and each of these portions was saturated with the chlorides of potassium, sodium, calcium, magnesium and hydrogen (HCl), respectively. Each of the so saturated portions was subdivided into smaller fractions which were heated at 25°, 50°, 75°, and 100° C. for 0, 5, 12, and 46 days respectively. The amount of the particular replaceable base with which the clay had been saturated and the total exchangeable bases were determined after each thermal treatment.

It was found that the amounts of replaceable potassium, calcium, and acid hydrogen decreased with prolonged treatment, whereas that of sodium and magnesium increased.

The amount of total exchangeable bases showed an increase in the potassium and acid hydrogen clays, and a decrease in the sodium, calcium, and magnesium clays upon prolonged thermal treatment.

The reasons for these markedly different behaviours of clays saturated with different cations are not well understood at present. An interpretation based on ionic radii is proposed.

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SUMARIO

El efecto del factor temperatura y del factor calor sobre la capacidad de los suelos para sufrir intercambio de iones (base-exchange) fué estudiado con muestras de coloides arcillosos (clay colloids) que estaban saturados con una de cada una de las siguientes bases: sodio, potasio, calcio, magnesio, e hidrógeno (ácido).

Cada una de las muestras así saturadas fué sometida a un tratamiento termal que variaba, para las distintas muestras, tanto en longitud de tiempo como en intensidad de calor (temperatura). Antes y después del tratamiento termal se determinó en cada muestra su capacidad para intercambiar el catión característico con el cual el coloide estaba saturado, así como también la capacidad total del coloide para intercambiar bases (total base-exchange capacity).

Los resultados fueron, brevemente, los siguientes:

Sodio—aumentó la cantidad intercambiable de sodio.
Calcio—aumentó la cantidad intercambiable de calcio.
Potasio—disminuyó la cantidad intercambiable de potasio.
Magnesio—disminuyó la cantidad intercambiable de magnesio.
Hidrógeno—aumentó la cantidad intercambiable de hidrógeno.

Este modo de comportarse no ha sido explicado claramente hasta la fecha. El autor hace notar, sin embargo, la relación que parece existir entre el radio iónico de las bases y su modo de comportarse hacia el calor:

Coloides saturados con metales de radio iónico relativamente grande (Na, Ca) demuestran un aumento en la cantidad de base intercambiable despúes de ser calentados. Aquellos coloides saturados con metales de radio iónico relativamente pequeño (K, Mg) sufren una disminución en la cantidad de base intercambiable al ser calentados.

PHOSPHORIC ACID AND SILICA OF PUERTO RICO SOILS

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One hundred and nine soil samples from three areas in the humid region of Puerto Rico are grouped into five textural soil classes according to their mechanical composition, irrespective of their altitudes, and data are reported for pH, total and available phosphoric acid and silica, supplemented also with some figures for volume weight and altitude (tables 1-6).

Location and sampling of soils. The following three areas of the humid region of Puerto Rico were chosen for this work:

1. Between the Arecibo and Manatí rivers including Utuado, Jayuya, Cialitos, Ciales, Florida, Arecibo and Barceloneta.

2. Between the Fajardo and Patillas rivers including Ceiba, Naguabo, Humacao, Las Piedras, Yabucoa, Maunabo and Patillas.

3. Around Caguas including Aguas Buenas, Gurabo, San Lorenzo and Las Cruces.

Soil survey maps were used for the location of the soil types. Samples to a depth of ten inches were taken with an auger in different places of the undisturbed field until a two-pound burlap bag was filled. The elevation of the field was read in a calibrated aneroid barometer.

Analytical methods. The analytical methods used were as follows:

DETERMINATION	METHOD
pH	Electrometric with quinhydrone
Volume weight	Cylinder (3)
Mechanical analysis	Bouyoucos hydrometer (2)
Total P_2O_5	Magnesium nitrate
Available P_2O_5 and SiO_2	1% Citric acid (1)
Total SiO_2	Sodium carbonate fusion

Available phosphoric acid and silica were determined in the same aliquot.

Textural grades. The 109 soil types were classified according to their mechanical composition (4) using as a basis the Bouyoucos system of soil separates: sands (1.00-0.05 mm.), silt (0.05-0.005 mm.), clay (<0.005 mm.). The soil types were grouped into five soil classes as follows: 3 sands (table 1), 19 sandy loams (table 2), 20 sandy clay loams (table 3), 14 clay loams (table 4) and 53 clays—1 sandy clay inclusive (table 5). The average values for volume weight, mechani-

TABLE 1. ACIDITY, MECHANICAL ANALYSIS, TOTAL AND AVAILABLE PHOSPHORIC AC AND SILICA OF THREE SANDS IN THE HUMID REGION OF PUERTO RICO

Soil Type	Location	Elevation (feet)	pH	Percentage on Dry Basis						
				Mechanical Analysis			Total		Availabl	
				Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	Si
Aguadilla sand	Km. 72.0 Naguabo-Humacao road	....	6.5	89.0	3.2	7.8	.051	74.61	.003	.0
Bayamón sand	Km. 73.5 Arecibo-Barceloneta road	173	8.1	85.6	2.8	11.6	.038	93.79	.002	.0
Bayamón sand	Km. 67.5 Arecibo-Barceloneta road	....	6.1	73.6	2.6	23.8	.065	80.48	.002	.0

cal analysis, total and available phosphoric acid and silica are given in table 6. The weight of the soil calculated from the volume weight, and the ratio of total to available phosphoric acid are also reported in that table.

TABLE 2. ACIDITY, VOLUME WEIGHT, MECHANICAL ANALYSIS, TOTAL AND AVAILABL PHOSPHORIC ACID AND SILICA OF NINETEEN SANDY LOAMS IN THE HUMID REGION O PUERTO RICO

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
Caguas sandy loam	Km. 58.2 Ceiba-Naguabo road just outside of Ceiba	30	7.9	1.70	68.0	22.6	9.4	.038	86.06	.003	.02
Candelero sandy loam	Yabucoa playa road about 1.5 km. from main road	53	5.5	1.58	72.4	14.0	13.6	.057	70.01	.003	.03
Candelero sandy loam shallow phase	Yabucoa playa road about 1 km. from main road	35	6.1	1.43	69.4	13.8	16.8	.071	66.97	.011	.04
Cayaguá sandy loam	Km. 1.8 San Lorenzo-Patillas road	480	5.3	1.48	58.8	24.4	16.8	.117	62.05	.041	.15
Ciales sandy loam	Colonia Ingenio, Yabucoa, at Cerro Santo Domingo	....	5.7	1.30	74.8	12.0	13.2	.107	59.33	.027	.05
Daguao sandy loam	Km. 108.5 Yabucoa-Maunabo road	117	6.4	1.47	70.2	12.4	17.4	.124	49.18	.012	.14
Maunabo sandy loam	Colonia Unión, Yabucoa, 1.5 km. from Yabucoa road at Don Paco	....	5.6	1.43	70.6	11.8	17.6	.083	61.78	.002	.17
Pandura sandy loam	Km. 103.6 Yabucoa-Maunabo road	572	5.4	1.48	66.2	17.8	16.0	.076	58.67	.003	.16
Pandura sandy loam	Km. 102.3 Yabucoa-Maunabo road	368	5.6	1.30	78.4	11.6	10.0	.147	62.31	.027	.09
Pandura sandy loam	Km. 107.3 Yabucoa-Maunabo road at Barrio Talante	358	6.0	1.29	70.4	15.8	13.8	.158	53.89	.031	.13
Pandura sandy loam	Km. 101.0 Yabucoa-Maunabo road	162	5.7	1.46	66.0	15.6	18.4	.062	63.07	.002	.08
Teja sandy loam	Yabucoa playa road about 1 km. from main road	....	5.6	1.40	68.0	19.6	12.4	.088	58.61	.002	.05
Toa sandy loam	Km. 10.0 San Lorenzo-Patillas road	600	5.3	1.39	62.8	22.4	14.8	.085	55.30	.006	.10

TABLE 2. *Continued*

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
...ado sandy ...oam	About ½ km. N. W. Central Santa Bárbara, Jayuya	1302	6.7	....	68.0	20.4	11.6	.120	59.11	.036	.233
...a Alta sandy ...oam	¼ Km. W. Florida	473	5.1	....	77.8	7.8	14.4	.120	84.24	.006	.020
...ri sandy loam	About ½ km. W. Central Santa Bárbara, Jayuya.	1202	5.6	....	56.0	28.8	15.2	.179	54.54	.038	.300
...ri sandy loam	About ½ km. N. W. Central Colombia, Maunabo	39	5.5	1.35	58.4	21.8	19.8	.155	58.10	.019	.200
...ri sandy loam	Ingenio road about .2 km. from Yabucoa road	....	6.9	1.52	74.8	12.0	13.2	.085	63.96	.012	.089
...abucoa sandy ...loam	Colonia Ingenio, Yabucoa	....	5.0	1.53	74.4	10.4	15.2	.140	67.04	.037	.049

TABLE 3. ACIDITY, VOLUME WEIGHT, MECHANICAL ANALYSIS, TOTAL AND AVAILABLE PHOSPHORIC ACID AND SILICA OF TWENTY SANDY CLAY LOAMS IN THE HUMID REGION OF PUERTO RICO

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
Alonso sandy clay loam	About ¾ km. S. W. Central Pasto Viejo, Humacao	154	6.1	1.43	50.8	25.6	23.6	.150	63.70	.006	.033
Almirante sandy clay loam	½ km. S. Florida	484	5.0	....	53.2	18.0	28.8	.289	59.89	.012	.022
Caguas sandy clay loam	Km. 1.0 Tomás de Castro road, Caguas	210	5.1	1.27	51.2	20.0	28.8	.065	76.64	.003	.064
Caguas sandy clay loam	Km. 2.9 Caguas-San Lorenzo road	90	4.3	1.40	55.2	20.0	24.8	.064	78.00	.007	.063
Cayaguá sandy clay loam	Km. 1.8 San Lorenzo-Patillas road	480	5.3	1.48	58.8	24.4	16.8	.117	62.05	.041	.153
Cayaguá sandy clay loam	Km. 9.0 Caguas-San Lorenzo road	310	4.6	1.46	57.2	14.4	28.4	.060	78.39	.003	.073
Cayaguá sandy clay loam	Km. 25.2 Las Piedras-Humacao road	210	4.9	1.59	51.2	28.0	20.8	.067	62.61	.003	.082
Daguao sandy clay loam	Km. 109.0 Yabucoa-Maunabo road, near Maunabo	39	6.7	1.42	58.0	15.8	26.2	.135	53.42	.007	.218
Humacao sandy clay loam	Km. 86.0 Humacao-Yabucoa road opposite entrance to Central Ejemplo	117	6.1	1.16	50.4	26.0	23.6	.135	65.14	.015	.083
Las Piedras sandy clay loam	Km. 24.1 Las Piedras-Humacao road	348	4.8	1.34	56.4	22.4	21.2	.122	70.47	.003	.056
Mariana sandy clay loam	Humacao-Antón Ruiz road at Barrio Mambiche Blanco	128	4.9	1.31	50.8	22.0	27.2	.154	55.57	.009	.045
Maunabo sandy clay loam	Km. 94.6 Yabucoa road	....	5.0	1.23	51.0	25.8	23.2	.160	54.41	.017	.079
Naranjito sandy clay loam	Km. 113.5 Maunabo-Patillas road at Cape Malapascua	200	7.4	1.14	64.4	21.6	14.0	.078	64.25	.002	.067

TABLE 3. *Continued*

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
Pandura sandy clay loam	Km. 104.8 Yabucoa-Maunabo road border line between Barrio Pica, Yabucoa and Barrio Talante, Maunabo	761	6.3	1.20	64.2	14.0	21.8	.130	62.65	.008	.08
Pandura sandy clay loam	Km. 105.8 Yabucoa-Maunabo road at Barrio Talante	591	6.4	1.37	54.8	24.0	21.2	.108	60.32	.002	.08
Pandura sandy clay loam	Km. 7.0 San Lorenzo-Patillas road	500	5.3	1.40	58.8	14.4	26.8	.116	62.43	.005	.11
Riverwash sandy clay loam	Km. 2.0 Borinquen road, Caguas	440	5.3	1.39	54.0	22.4	23.6	.194	63.68	.016	.13
Sabana Seca sandy clay loam	Between km. 79.3 and 79.4 Arecibo-Barceloneta road	17	8.2	....	60.2	11.8	28.0	.133	73.62	.004	.05
Talante sandy clay loam	About ¼ km. Yabucoa-Calabazas road	....	5.2	.98	53.0	20.2	26.8	.141	53.81	.004	.16
Teja sandy clay loam	Km. 88.2 Humacao-Yabucoa road	....	5.1	1.40	52.8	26.4	20.8	.079	64.78	.004	.05

TABLE 4. ACIDITY, VOLUME WEIGHT, MECHANICAL ANALYSIS, TOTAL AND AVAILABLE PHOSPHORIC ACID AND SILICA IN FOURTEEN CLAY LOAMS IN THE HUMID REGION OF PUERTO RICO

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
Candelero clay loam	Km. 89.3 Humacao-Yabucoa road	117	4.8	1.22	48.6	30.2	21.2	.089	60.28	.014	.067
Coloso clay loam	Km. 65.4 Ceiba-Naguabo road at Quebrada Palma	....	6.1	1.32	48.8	23.6	27.6	.115	65.01	.005	.151
Coloso clay loam	Km. 0.8 Naguabo Playa to Naguabo road at Central Triunfo	....	5.4	1.34	26.6	44.2	29.2	.138	60.22	.007	.239
Daguao clay loam	Entrance of road to Central Ejemplo, Humacao	167	5.5	1.30	49.0	30.2	20.8	.133	40.27	.004	.096
Estación clay loam	Km. 11.9 Manati-Ciales road	367	7.4	....	48.0	26.4	25.6	.224	53.61	.029	.656
Humacao clay loam	Entrance of road to Central Ejemplo, Humacao	117	5.4	1.29	45.2	30.0	24.8	.090	58.34	.002	.083
Juncos clay loam	Km. 4.7 Caguas-San Lorenzo road	270	5.7	1.35	34.8	36.0	29.2	.087	72.75	.005	.096
Mariana clay loam	Km. 60.9 Ceiba-Naguabo road back of Carlos Carlo Figueroa School	118	5.3	1.62	36.8	38.0	25.2	.018	74.93	.002	.277
Río Arriba clay loam	Humacao-Antón Ruiz road at Barrio Mambiche Blanco	136	6.1	1.41	41.6	30.4	28.0	.167	63.84	.003	.045

TABLE 4. *Continued*

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
...bana clay loam	Km. 112.8 Maunabo-Patillas road	130	7.1	1.10	48.4	24.2	27.4	.078	56.15	.003	.101
...a clay loam	Km. 0.1 Tomás de Castro road, Caguas	180	5.9	1.18	48.0	24.0	28.0	.137	62.50	.011	.174
...a clay loam	Km. 1.5 Caguas-San Lorenzo road	80	5.8	1.40	50.8	24.0	25.2	.119	63.70	.007	.176
...a clay loam	Humacao-Antón Ruiz road at Barrio Mambiche Blanco	109	6.4	1.38	42.6	29.4	28.0	.135	68.14	.003	.076
...a clay loam	Km. 0.7 Humacao-Antón Ruiz road at Perseverancia farm	107	6.4	1.09	41.2	24.8	34.0	.100	54.01	.002	.093

TABLE 5. ACIDITY, VOLUME WEIGHT, MECHANICAL ANALYSIS, TOTAL AND AVAILABLE PHOSPHORIC ACID AND SILICA, OF FIFTY-THREE CLAYS IN THE HUMID REGION OF PUERTO RICO

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
Alonso clay	About km. 19.5 Ciales-Jayuya road	1034	5.4	....	28.2	33.0	38.8	.068	48.63	.002	.080
Alonso clay smooth phase	About km. 21.2 Florida-Jayuya road at Barrio Piedra Gorda School	759	4.7	....	26.6	28.0	45.4	.065	66.35	.001	.044
Caguas clay	Km. 37.7 Caguas-Cayey road	280	6.5	....	31.2	32.8	36.0	.113	76.49	.003	.074
Caguas clay	Km. 9.0 San Lorenzo-Patillas road	620	5.2	1.46	42.8	20.4	36.8	.089	67.44	.001	.065
Cayaguá clay	Km. 5.7 San Lorenzo-Patillas road at entrance of Jaguar road	600	5.7	1.25	24.8	34.4	40.8	.106	72.38	.006	.202
Catalina clay	About km. 18.5 Ciales-Jayuya road	940	5.1	....	32.0	24.0	44.0	.073	56.09	.004	.036
Catalina clay steep phase	0.5 km. E. Hacienda Piedra Gorda, Florida-Jayuya road	685	5.1	....	35.6	22.4	42.0	.139	45.71	.012	.077
Ciales clay	Km. 15.0 Ciales-Jayuya road	639	4.6	....	25.2	28.4	46.4	.132	48.71	.008	.068
Ciales clay	Km. 12.5 Manati-Ciales road	367	7.6	....	35.6	26.4	38.0	.153	61.35	.012	.131
Cialitos clay	Km. 47.9 Caguas-Cayey road	1525	4.5	1.24	23.6	34.0	42.4	.184	70.60	.002	.025
Cialitos clay	Km. 45.5 Caguas-Cayey road	1200	4.2	1.42	35.6	24.0	40.4	.169	69.88	.002	.026
Cialitos clay	About 1 km. S. E. Hacienda Piedra Gorda, Florida-Jayuya road	892	4.9	....	29.8	32.8	37.4	.084	57.50	.005	.410
Cialitos clay	Between km. 20.2-20.3 Florida-Jayuya road	685	5.8	....	35.6	30.4	34.0	.056	61.68	.014	.219
Cialitos clay steep phase	Camino Borinquen at km. 5.3 Naranjito road	700	5.2	1.47	40.0	28.4	31.6	.152	62.16	.006	.157

TABLE 5. *Continued*

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
Coloso clay	Km. 0.5 Humacao-Antón Ruiz road at Perseverancia farm	107	7.4	1.24	34.4	10.0	55.6	.121	51.71	.006	.124
Coloso clay	Km. 112.2 Maunabo-Patillas road	39	8.1	1.20	38.8	28.0	33.2	.088	59.63	.011	.173
Coloso clay	About ¾ km. S. W. Central Plazuela, Barceloneta	23	7.0	....	24.0	32.8	43.2	.216	53.05	.014	.484
Coloso clay	About ¼ km. E. Central Pasto Viejo, Humacao	16	4.9	1.15	38.6	27.8	33.6	.244	62.25	.018	.048
Coto clay	Km. 14.6 Florida-Jayuya road	723	8.2	....	42.8	24.0	33.2	.460	26.83	.017	.051
Coto clay	Km. 12.1 Florida-Jayuya road	555	8.1	....	21.0	20.8	58.2	.525	39.36	.017	.044
Daguao clay	Km. 65.0 Ceiba-Naguabo road at Colonia Esperanza Barrio Daguao	116	6.3	1.40	24.4	30.4	45.2	.056	49.26	.003	.060
Espinosa clay	Km. 78.1 Arecibo-Barceloneta road	90	7.4	....	50.0	10.8	39.2	.119	64.16	.002	.064
Espinosa clay	Km. 74.8 Arecibo-Barceloneta road	....	6.1	....	51.4	11.4	37.2	.086	67.27	.002	.035
Irurena clay	Colonia Unión about 2 km. from Yabucoa road at Moquilla	....	6.1	1.15	44.2	23.8	32.0	.162	53.88	.009	.235
Juncos clay	About 1 km. S. E. Hacienda Piedra Gorda, Florida-Jayuya road	891	5.9	....	47.0	24.2	28.8	.057	52.95	.004	.886
Juncos clay	Borinquen road, Caguas, about 0.6 km. Naranjito road	525	5.6	1.28	26.0	32.4	41.6	.113	69.02	.003	.072
Juncos clay	Km. 40.3 Caguas-Cayey road	390	6.5	1.34	27.2	28.8	44.0	.106	56.49	.002	.174
Juncos clay	Km. 1.6 Caguas-Tomás de Castro road	280	6.0	1.36	26.8	34.0	39.2	.073	58.51	.004	.166
Juncos clay	Km. 8.0 Caguas-San Lorenzo road	280	6.3	1.24	28.8	30.8	40.4	.118	66.43	.006	.175
Las Piedras clay	Km. 2.0 Jaguar road, San Lorenzo	700	6.2	1.05	38.8	30.4	30.8	.155	66.93	.004	.099
Las Piedras clay	Km. 6.0 Caguas-San Lorenzo road	275	6.7	1.07	30.4	28.8	40.8	.142	62.25	.007	.169
Los Guineos clay	Km. 27.8 Casa Blanca-Jayuya road	2134	5.0	....	31.8	37.4	30.8	.187	34.77	.005	.065
Los Guineos clay	Km. 30.9 Ciales-Jayuya road	1679	4.5	....	29.2	24.0	46.8	.141	35.29	.001	.061
Múcara clay	Km. 5.7 Caguas-Tomás de Castro road	870	5.5	1.29	28.8	28.4	42.8	.095	57.07	.003	.154
Múcara clay	Km. 43.1 Caguas-Cayey road	770	5.1	1.35	43.6	26.8	29.6	.097	53.09	.003	.094
Múcara clay	Borinquen road, Caguas, at km. 3.8 camino Naranjito	680	5.7	1.07	31.6	30.4	38.0	.148	61.61	.001	.173
Múcara clay	Km. 3.0 Caguas-Tomás de Castro road	600	5.7	1.27	30.8	32.0	37.2	.091	52.90	.004	.181

TABLE 5. *Continued*

Soil Type	Location	Elevation (feet)	pH	Volume weight	Percentage on Dry Basis						
					Mechanical Analysis			Total		Available	
					Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2
Múcara clay	Km. 42.0 Caguas-Cayey road at entrance of Camino Borinquen	510	5.2	1.48	35.6	26.8	37.6	.201	54.18	.003	.155
Múcara clay	Km. 7.0 Caguas-Tomás de Castro road	280	5.2	1.07	34.8	26.4	38.8	.144	56.79	.005	.107
Múcara clay steep phase	Km. 68.0 Ceiba-Naguabo road	80	6.1	1.15	36.4	4.8	58.8	.053	53.11	.002	.123
Múcara sandy clay	Km. 1.2 Humacao-Antón Ruiz road, at Barrio Pitijalla	173	6.3	1.17	53.2	12.8	34.0	.071	49.94	.002	.091
Naranjito clay	Borinquen road, Caguas, at km. 5.1 Naranjito road	620	5.1	1.14	29.6	26.4	44.0	.087	60.70	.001	.086
Reparada clay	Km. 78.7 Naguabo road at Colonia Santa Teresa	....	4.7	.43	48.8	20.4	30.8	.233	41.34	.034	.086
Rio Piedras clay	About 21.2 Florida-Jayuya road at Barrio Piedra Gorda School	762	6.3	....	33.6	27.6	38.8	.068	53.71	.002	.057
Sabana clay	Km. 71.4 Naguabo-Humacao road	70	4.6	1.33	46.4	22.0	31.6	.128	64.64	.004	.032
Sabana Seca clay	Km. 1.6 Borinquen road, Caguas	480	6.2	1.32	27.2	30.8	42.0	.112	58.97	.003	.140
Toa clay	Km. 1.3 Jaguar road, San Lorenzo	590	5.7	1.08	24.8	38.4	36.8	.106	57.35	.005	.421
Toa clay	Km. 41.75 Caguas-Cayey road	420	5.3	1.36	45.2	21.2	33.6	.164	58.92	.005	.200
Toa clay	Km. 1.0 Borinquen road, Caguas	420	5.8	1.24	31.6	28.4	40.0	.099	63.16	.008	.109
Toa clay	About ½ km. E. junction road No. 2 to Barceloneta	23	6.0	....	27.2	36.4	36.4	.222	52.72	.024	.474
Toa clay	Km. 82.3 Cambalache-Arecibo road	17	7.9	....	36.4	30.8	32.8	.208	55.30	.037	.321
Torres clay	Km. 0.4 Borinquen road, Caguas	500	7.5	1.39	19.2	28.8	52.0	.154	55.73	.008	.204
Yabucoa clay	About ¾ km. Yabucoa-Calabazas road on Luis Toro's farm	....	5.2	1.17	41.6	24.4	34.0	.167	51.35	.006	.163

TABLE 6. AVERAGE VALUES FOR VOLUME WEIGHT, WEIGHT OF ACRE PLOW DEPTH, MECHANICAL ANALYSIS, TOTAL AND AVAILABLE PHOSPHORIC ACID AND SILICA AND RATIO OF TOTAL TO AVAILABLE PHOSPHORIC ACID OF ONE HUNDRED NINE SOILS IN THE HUMID REGION OF PUERTO RICO CLASSIFIED INTO FIVE TEXTURAL SOIL CLASSES

Number of Samples	Textural Soil Class	Volume Weight	Weight of acre plow depth 6⅔ inches, lbs.	Percentage on Dry Basis							Total to Available P_2O_5 ratio
				Mechanical Analysis			Total		Available		
				Sand	Silt	Clay	P_2O_5	SiO_2	P_2O_5	SiO_2	
3	Sands	....*	.....*	82.73	2.87	14.40	.051	82.96	.002	.021	22.2
19	Sandy loams	1.43	2,159,414	68.71	16.57	14.72	.106	62.85	.017	.114	6.3
20	Sandy clay loams	1.33	2,008,406	55.32	20.86	23.82	.125	64.29	.009	.087	13.9
14	Clay loams	1.31	1,978,205	43.60	29.67	26.73	.116	60.98	.007	.166	16.6
53	Clays	1.23	1,857,398	34.12	26.68	39.20	.140	56.75	.007	.154	20.0

* Not determined.

SUMMARY

One hundred and nine soil types from the humid region of Puerto Rico were classified on the basis of their mechanical analysis into five soil classes—sands, sandy loams, sandy clay loams, clay loams, clays—and were analyzed for pH, volume weight, total and available phosphoric acid and silica. The clay loams weigh about two million pounds per acre plow depth of 6⅔ inches, the sandy loams weigh about 5% more and the clays weigh about 10% less. The total phosphoric acid varies from .051% in the sands to .140% in the clays. The available phosphoric acid varies from .007% in the clays to .017% in the sandy loams. The total to available P_2O_5 ratio varies from 6.3 in the sandy loams to 20.0 in the clays. The total silica varies from 56.75% in the clays to 82.96% in the sands. The available silica varies from .021% in the sands to .166% in the clay loams.

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SUMARIO

Ciento nueve tipos de suelos en la zona húmeda de Puerto Rico se clasificaron a base del análisis mecánico en cinco clases de suelos: arenas, arenosolómicas, arenoarcillosolómicas, arcillosolómicas, arcillas, y se les hicieron determinaciones de pH, peso por volumen, ácido fosfórico y sílica total y asimilable. El promedio de los valores indica que las clases arcillosolómicas pesan cerca de dos millones de libras por acre arable (6⅔ pulgadas de espesor), las arenosolómicas pesan como 5% más y las arcillas pesan coma 10% menos; el ácido fosfórico total varía desde .051% en les arenas a .140% en las arcillas; el ácido fosfórico asimilable varía desde .007% en las arcillas a .017% en las clases arenosolómicas; la proporción de ácido fosfórico total a asimilable varía desde 6.3 en las clases arenosolómicas a 20.0 en las arcillas; la sílica total varía desde 56.75% en las arcillas a 82.96% en las arenas; la sílica asimilable varía desde .021% en las arenas a .166% en las clases arcillosolómicas.